AFRL-VS-TR-2002-1540

Analysis of Electric Field Data in the Inner Magnetosphere

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15 Feb 2000

Final Report

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REPORT DOCUMENTATION PAGE	*Form Approved* *OMB No. 0704-0188*

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	February 2000	FINAL REPORT

4. TITLE AND SUBTITLE
Analysis of Electric Field Data in the Inner Magnetosphere

5. FUNDING NUMBERS
PE: 61102F
PR: 2311
TA: GA
WU: MN

Contract #: F19628-96-C-0074

6. AUTHOR(S)
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Research Laboratory
29 Randolph Road
Hanscom AFB MA 01731-3010

Contract Manager: Shu Lai/VSBXT

10. SPONSORING/MONITORING AGENCY REPORT NUMBER
AFRL-VS-TR-2002-1540

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for Public Release, Distribution Unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*
Analysis of the CRRES spacecraft electric field data provides better understanding of the role of the electric field in the transport and energization of particles at and within geosynchronous orbit in support of the efforts of scientists at Air Force Research Laboratory to produce dynamic models of energetic particle fluxes.

14. SUBJECT TERMS
Electric field Ring current
Inner magnetosphere
CRRES

15. NUMBER OF PAGES

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
UNCLASSIFIED	UNCLASSIFIED	UNCLASSIFIED	SAR

Standard Form 298 (Rev. 2-89) (EG)
Prescribed by ANSI Std. 239.18
Designed using Perform Pro, WHS/DIOR, Oct 94

Final Report for Contract #F19628-96-C-0074

Feb. 15, 2000

Title: An Analysis of Electric Fields in the Inner Magnetosphere

Purpose: The purpose of this contract is to analyze electric field data from the CRRES spacecraft in an effort to understand the role of the electric field in the transport and energization of particles at and within geosynchronous orbit in support of the efforts of scientists at Phillips Laboratory to produce dynamic models of energetic particle fluxes.

Work Performed under contract:

I. Our analysis of the CRRES data provided the first direct link between ring current formation during major geomagnetic storms and the large-scale electric field in the inner magnetosphere.

During major geomagnetic storms the population of moderately energetic ions (1 keV to a few hundred keV) in the inner magnetosphere increases dramatically in a matter of hours, with up to an order of magnitude increase in the associated current flowing westward around the earth. The origin of these particles and the exact mechanisms by which they are energized and transported to the inner magnetosphere are a subject of debate. It had long been hypothesized that a major contributor to this enhancement of the "ring current" energetic particle population could be the transport of hot ions from the plasma sheet via the large-scale, slowly-varying electric field in the inner and middle magnetosphere.

The CRRES mission was the first to thoroughly explore the inner magnetosphere while equipped with a sensitive electric field detector and a full suite of particle instruments. During the major geomagnetic storms of 1991 CRRES returned simultaneous measurements of the electric field, the local energetic particle fluxes, and the magnetic field (which gives information about the ring current in a more global sense). This data showed that during geomagnetic storms there was a one-to-one correspondence between ring current enhancement (as measured by the *Dst* index and the local magnetic field perturbation due to the current) and the presence of enhanced large-scale electric fields an order of magnitude larger than quiet-time levels. These enhanced electric fields were also observed to penetrate much deeper into the inner magnetosphere than previously believed from indirect measurement and theory. Finally, the electric field was observed to maximize deep in the inner magnetosphere, instead of decreasing near the Earth as conventional wisdom would predict. This maxima in the large-scale electric field occurred throughout the main phase while the ring current was being enhanced as well as during the recovery phase of the storms. The maxima also occurred where the ring current energy density was largest, indicating that it was much more efficient at energizing particles than had previously been believed.

This work was published in:

J.R. Wygant, D. Rowland, H. Singer, M. Temerin, F. Mozer, and M.K. Hudson, "Experimental evidence on the role of the large spatial scale electric field in creating the ring current," *J. Geophys. Res.*, **103,** 29527, 1998.

The PI, **John Wygant** gave the following invited talks based on this work:

- "Electric fields during the main phase of major geomagnetic storms," NSF GEM conference, Snowmass, CO, June 1997.
- "Particle Acceleration in the inner magnetosphere," Laboratory for Atmospheric and Space Physics, University of Colorado, Fall 1997.
- "Dynamics of the large scale electric field in the inner magnetosphere," Plenary Session, NSF GEM Conference, Snowmass CO, Summer 1998.
- "Particle acceleration during major geomagnetic storms," Astrophysics Colloquium, University of Minnesota, Spring 1999.
- "Electric fields in the inner magnetosphere," AGU meeting, Spring 1999.
- "Dynamics of Particle Acceleration in the inner magnetosphere," First SRAMP Conference, Sapporo, Japan, to be held October, 2000.

Related work is presented in a paper to be submitted to the *Journal of Geophysical Research* in 2000:

A. Korth, R.H.W. Friedel, C.G. Mouikis, J.F. Fennell, J.R. Wygant, H. Korth, "Comprehensive particle and field observations of magnetic storms at different local times from the CRRES spacecraft"

II. Statistical analysis of the CRRES electric field data shows that the stormtime maxima in the inner-magnetospheric electric field is present even at moderate activity levels.

The nine months of electric field data from the CRRES mission were binned by geomagnetic activity and radial distance from Earth in order to examine the behavior of the electric field distribution in the inner magnetosphere that was originally observed during major geomagnetic storms. A systematic development of the radial profile of the electric field with increasing activity was discovered, with Volland-Stern models reflecting the situation accurately at very low activity levels, a transition region where the electric field penetrated deeper in and was more uniform, and the development above Kp of 3 of a local maxima in the magnitude of the large-scale electric field between L=2.5 and L=5. As activity levels increased, this maxima grew in size (in an absolute sense and relative to the electric field magnitude outside of L=5) and moved earthwards. Our

analysis of the electric field data also provided the first *in-situ* evidence of ring current shielding in the inner magnetosphere during quiet times.

This work is published in:

D.E. Rowland and J.R. Wygant, "The dependence of the large scale inner-magnetospheric electric field on geomagnetic activity," *J. Geophys. Res.*, **102,** 14959, 1998.

and was presented in the following posters:

- D.E. Rowland, M.T. Johnson, J.R. Wygant, F.S. Mozer, M. Temerin, and H. Singer, "Transient and steady-state convection in the inner magnetosphere," AGU Fall 1996.
- D.E. Rowland, J.R. Wygant, H. Singer, "The large-scale electric field in the inner magnetosphere and its relation to geomagnetic storms and the ring current," GEM 1997 workshop.

III. The inner edge of the plasma sheet marks a boundary between weaker turbulent flows in the plasma sheet and strong flows Earthward of this edge.

Comparison of simultaneous particle and electric field measurements near the plasma sheet boundary suggest rich phenomenology that has not been fully explored. The electric field in the near-earth plasma sheet is weak and turbulent, but as CRRES crosses the plasma sheet boundary moving Earthwards it often observed a striking increase in the electric field magnitude, with a development of more laminar flow. A manuscript describing these observations is currently being revised.

IV. The first 2-D vector maps of the large-scale electric fields during periods of high activity (Kp > 6) have been produced and show strong flows through the inner magnetosphere, with sharp boundaries between Earthward and tangential flow and flow enhancements near where the ring current density is a maximum.

Vector maps of the large-scale electric field during periods of high activity show generally laminar flow which is much stronger than that during quiet times. The feature which showed up as an enhancement in the electric field magnitude deep in the inner magnetosphere is resolved as a sharp boundary at which the electric field magnitude increases and the direction of the electric field changes from a sense that creates Earthward flow to one that produces more azimuthal flow. These vector maps are included in a manuscript that is currently being written and should be submitted to the *Journal of Geophysical Research* sometime this year.

V. Progress was made towards development of an empirical model of the inner-magnetospheric electric field during major storms based on CRRES EFI data.

This model is still in the developing stages, with outstanding issues related to calculation of electric potentials, resolving lack of coverage on the morning side, and issues relating to fitting parameters. The model is based on averages of the CRRES vector electric field data, binned according to location and geomagnetic activity.

VI. Preliminary results from a 2-D test particle simulation suggest that the distribution of electric potentials in the inner magnetosphere is very important in determining the final ring current enhancement. Comparisons of the ring current enhancement by adiabatic transport of plasma sheet ions under a uniform dawn-dusk field and the Volland-Stern electric field (a standard model) to the transport under an electric field consistent with the CRRES measurements shows that a much smaller cross-polar cap potential drop is necessary to produce the same ring current energization. In addition we have begun to study the role of transient electric fields in energizing ring current particles.

Some of this work was presented in the following poster:

- D.E. Rowland, J.R. Wygant, M. Temerin, H. Singer, A. Korth, "Large Transient electric fields observed during major geomagnetic storms in the inner magnetosphere," AGU Spring 1999.

VII. Large transient electric fields associated with energetic particle injection and magnetic field reconfigurations are common during major storms, with extremely high occurrence frequencies reaching one event every twenty minutes and occurring at all local times covered by the CRRES electric field data (postmidnight around to 15:00 hours MLT across the dusk side). The ExB velocities associated with these events have strong Earthward components as well as Poynting fluxes on the order of 1 mW/m^2 directed towards the ionosphere along magnetic field lines.

This work has been presented on the following posters:

- D.E. Rowland and J.R. Wygant, "CRRES observations of large transient electric fields and implications for ring current formation," AGU Fall 1997.

- D.E. Rowland, J.R. Wygant, "Stormtime electric fields in the inner magnetosphere," GEM 1998.

This work is included in a manuscript which is currently being written and should be submitted to the *Journal of Geophysical Research* sometime this year.

VIII. Radial Diffusion coefficients calculated from the directly measured electric fields can be an order of magnitude or more higher than previously believed during major geomagnetic storms.

The early analysis of the CRRES data regarding this topic was performed at Minnesota by John Wygant and Mike Johnson, demonstrating that radial diffusion

coefficients could be dramatically enhanced during major geomagnetic storms, This enhanced radial diffusion should serve to modify radiation belt and energetic ring current ion populations and transport strongly relative to more typical conditions during quiet times. For most of the contract period, Minnesota has served in an advisory role on this topic, providing information about the dataset and a cleaned up version of the dataset which has data quality flags included.

IX. Software development of the CRRES EFI PAPCO module:

PAPCO is a software package running under IDL and developed by Reiner Friedel (currently at Los Alamos) that facilitates the displaying and analysis of data from multiple sources simultaneously. This contract supported Doug Rowland's travel to Los Alamos for a PAPCO workshop and his effort in developing a module to display and analyze CRRES electric field data. This PAPCO module is now freely available via anonymous ftp or on the world wide web.

Other papers that were supported by Minnesota CRRES electric field data analysis during the contract period:

Fraser, B.J., H.J. Singer, W.J. Hughes, J.R. Wygant, R. Anderson, and D. Hu, "CRRES Poynting flux vector observations of electromagnetic ion cyclotron waves near the plasmapause," *J. Geophys. Res.*, **101,** 15331, 1996.

M.K. Hudson, S.R. Elkington, J.G. Lyon, V.A. Marchenko, I. Roth, M. Temerin, J.B. Blake, M.S. Gussenhoven, and J.R. Wygant, "Simulation of radiation belt formation during sudden storm commencements, *J. Geophys. Res.*, **102,** 14087, 1997.

W.I. Imhof, J. Mobilia, H.D. Voss, H.L. Collin, W. Walt, R. Anderson, J. Wygant, "Association of waves with narrow particle dropouts in the outer radiation belts," *J. Geophys. Res.*, **102,** 11429, 1997.